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# LQS report

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LARP Collaboration Meeting

FNAL

October 27, 2008

# Outline

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- Task goals
- Magnet design and assembly procedure
- Magnetic and mechanical analysis
- Assembly, loading, and cool-down of a 850 mm long segment with dummy coils
- Assembly of full-length shell-yoke sub-assembly
- Conclusions and next steps

# Task goals

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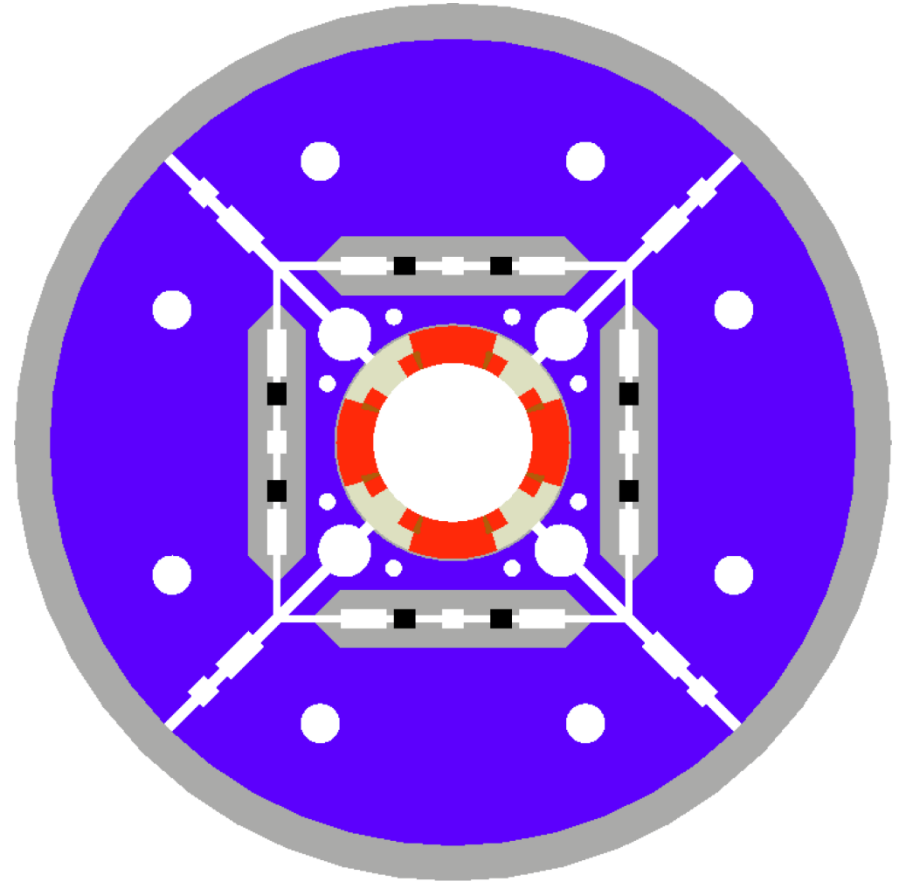
- Mechanical and magnetic analysis of LQS01
- Engineering design and procurement of support structure and handling, lifting, and tilting tooling
- Assembly, loading, and cool-down to 77 K of
  - 850 mm long segment with dummy coils
  - Full-length structure with dummy coils
- Assembly, load, and test of LQS01

# Magnet design

## Cross-section

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- 20 mm thick Al shell
- 4-split iron yoke
  - Gap keys and auxiliary bladders
  - Holes for tie rods
- Iron pads
  - Holes for coil end support and tie rods
- Iron masters
  - 2 bladders
  - 2 interference keys
- G10 sheet between coil and pad laminations

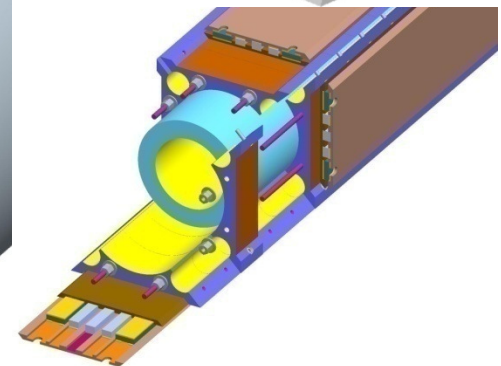
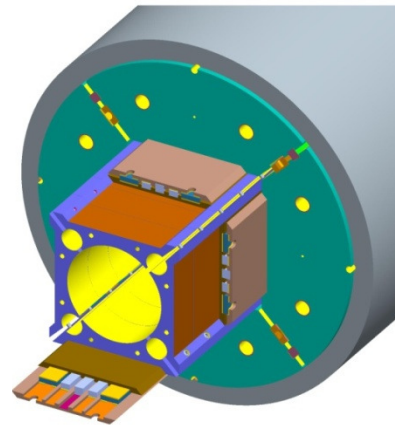
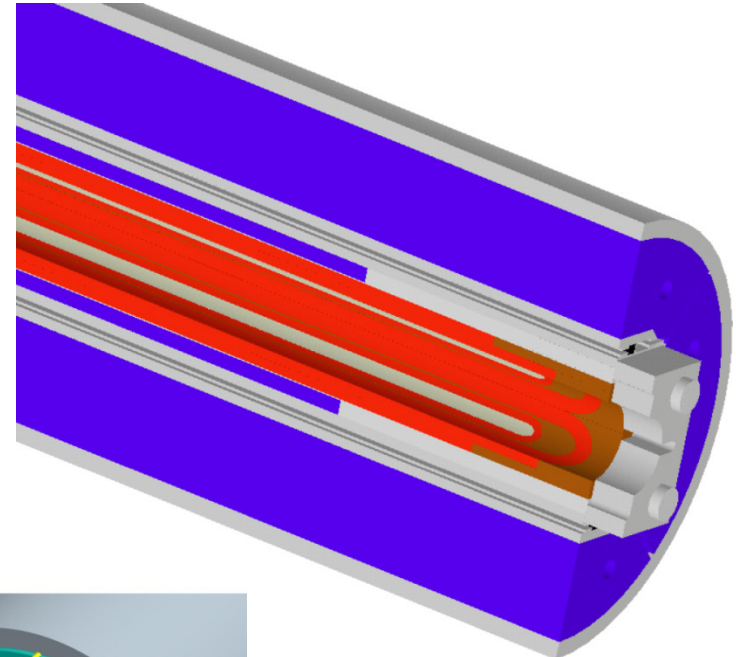




# Magnet design

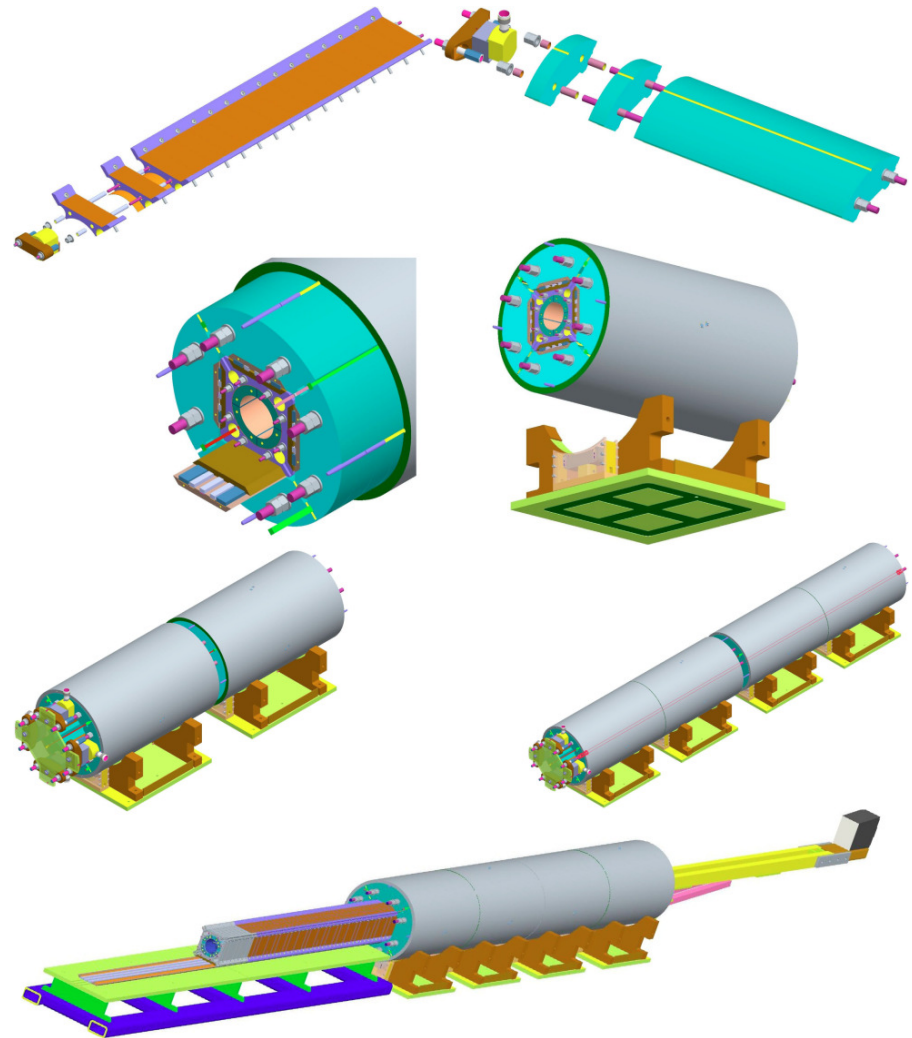
## 3D components

- 4 shell segments, 0.85 m long
- Yoke laminations, 50 mm thick with 3.4 m long tie rods
- Iron pad laminations, 50 mm thick with 3.4 m long tie rods
- Iron masters, 2 x 1.7 m long
  - Easy insertion and removal of coil pack (large clearance)
  - Continuous surface
  - Pad-yoke alignment
  - Improved tolerances



# Assembly procedure

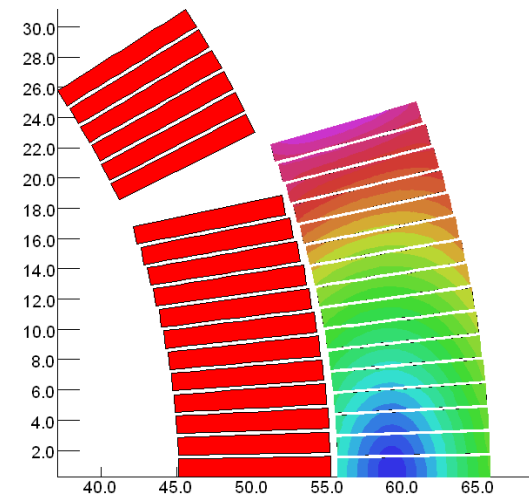
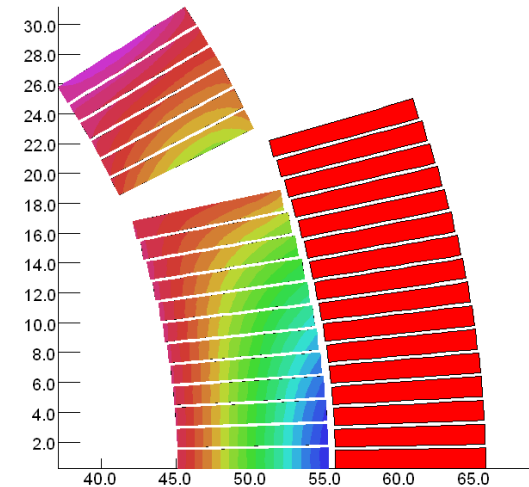
- Alignment of pad and yoke laminations with bushings
  - Insertion of tie rods
  - Pre-tension with piston
- Assembly of 850 mm long segments
- Joining of segments with air pallets
  - Alignment by shell-yoke pins
- Insertion of coil-pad sub-assembly with masters



# 2D magnetic analysis

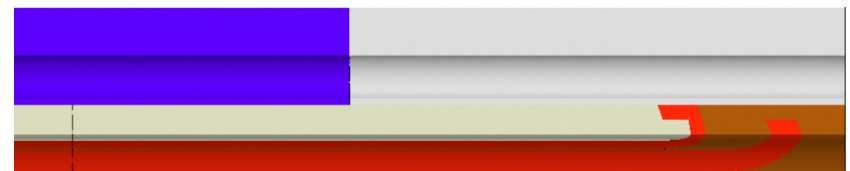
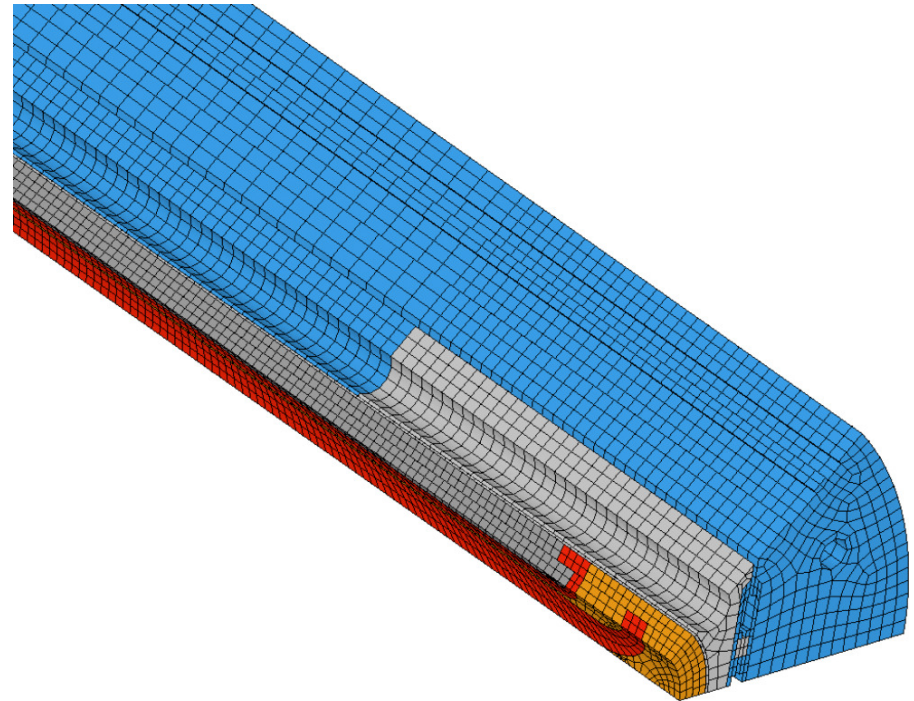
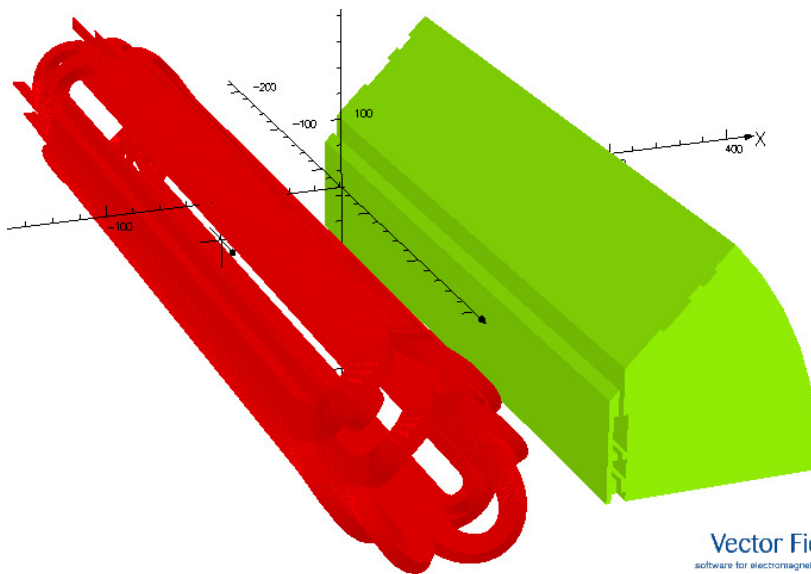
- $J_c$  of 2800 A/mm<sup>2</sup> (4.2 K, 12 T)
- About 2 T difference between layer 1 and layer 2

Temp.	Current	Gradient	Layer 1	Layer 2	Stored energy
			Peak field	Peak field	
K	kA	T/m	T	T	kJ/m
4.5	13.76	240	12.29	10.52	457
1.9	15.16	262	13.43	11.48	559



# 3D magnetic analysis

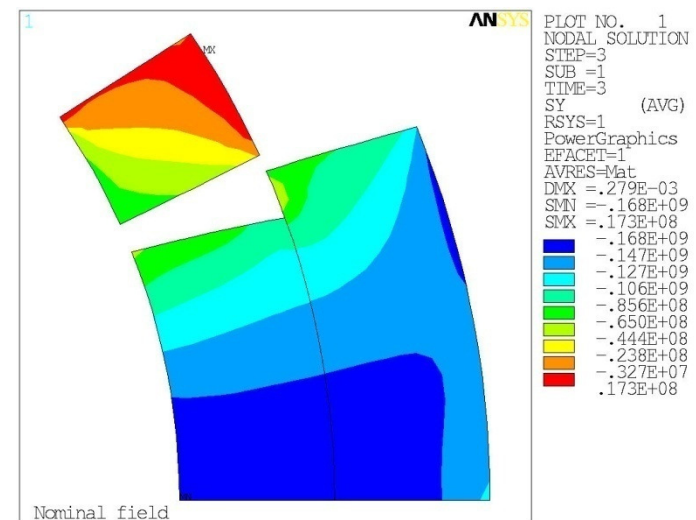
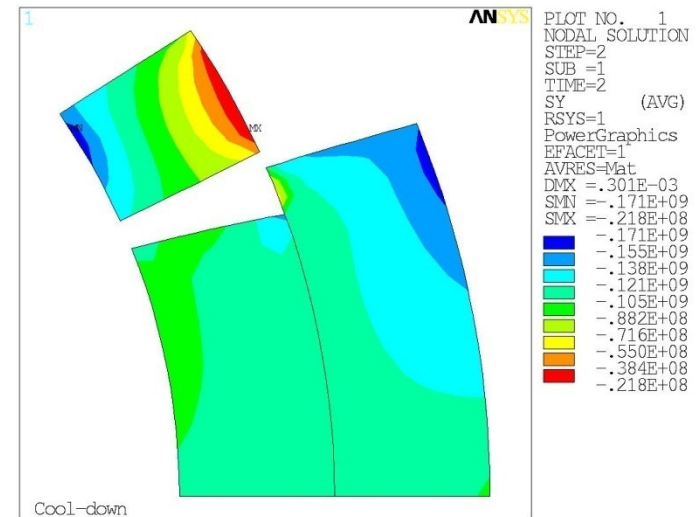
- Peak field in the end located on pole turn, layer 1
- Stainless steel pad 100 mm before end of straight section
  - Same peak field in the straight section and end



Vector Fields  
software for electromagnetic design

# 2D mechanical analysis

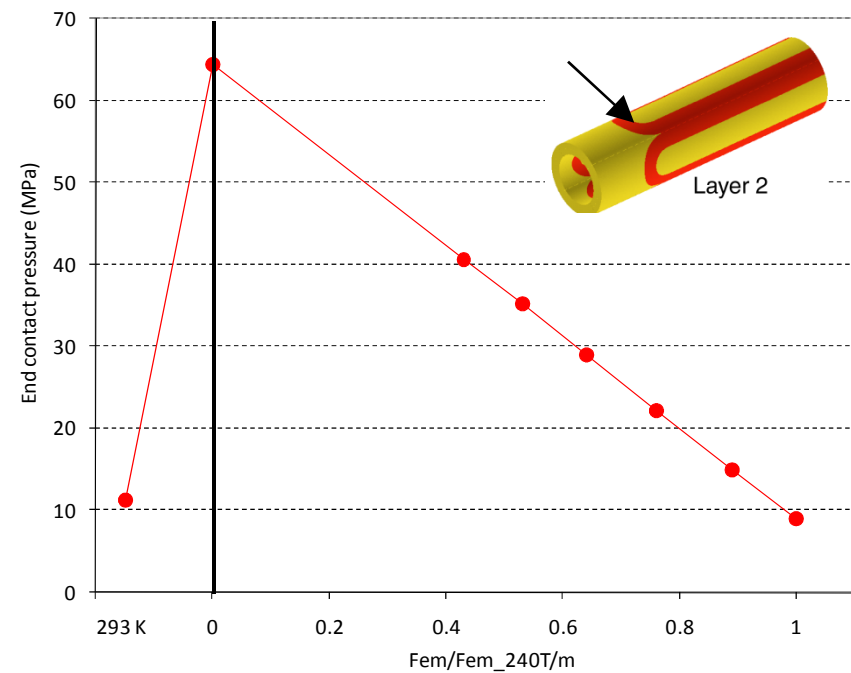
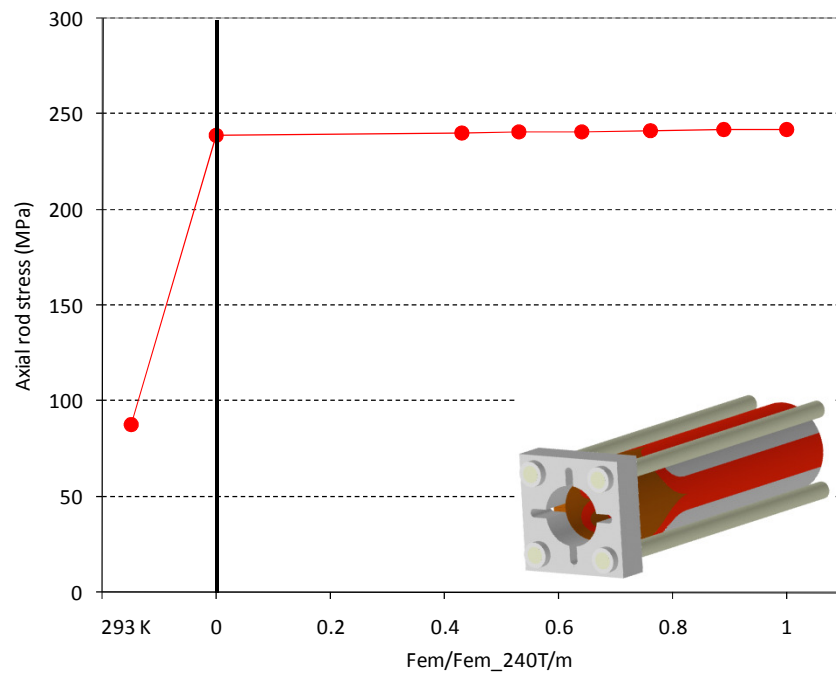
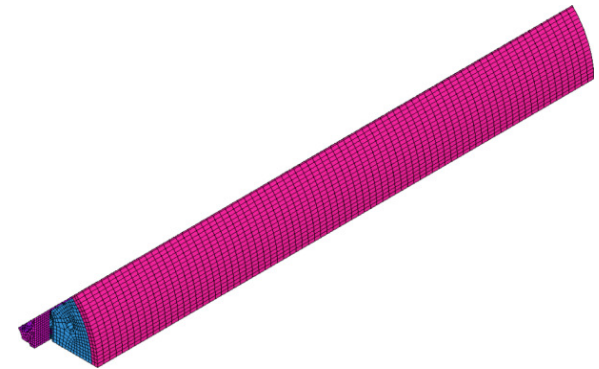
- No gap pole-coil at 240 T/m
- Coil peak stress at 4.5 K
  - Pole area, inner radius, layer 1
    - 171 MPa
- Coil peak stress at 240 T/m
  - Mid-plane, inner radius, layer 1
    - 168 MPa
- Key position optimized to minimize coil stress after cool-down and at 240 T/m
- <150 MPa of coil peak stress assuming 220 T/m





# 3D mechanical analysis

- No gap pole-coil at 240 T/m
- Axial e.m. force: 471 kN
- Stainless steel rod pre-tension: 88 MPa (178 kN)
- Rod stress at 4.5 K: 239 MPa (484 kN)
- 65 MPa of contact press. after cool-down



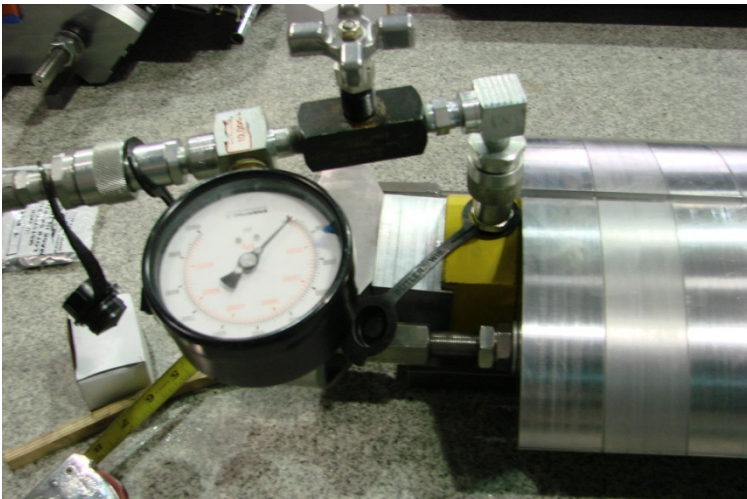
# Outline

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- Task goals
- Magnet design and assembly procedure
- Magnetic and mechanical analysis
- Assembly, loading, and cool-down of a 850 mm long segment with dummy coils
- Assembly of full-length shell-yoke sub-assembly
- Conclusions and next steps

# Assembly and loading of 850 mm long segment

## Stacking pad and yoke laminations



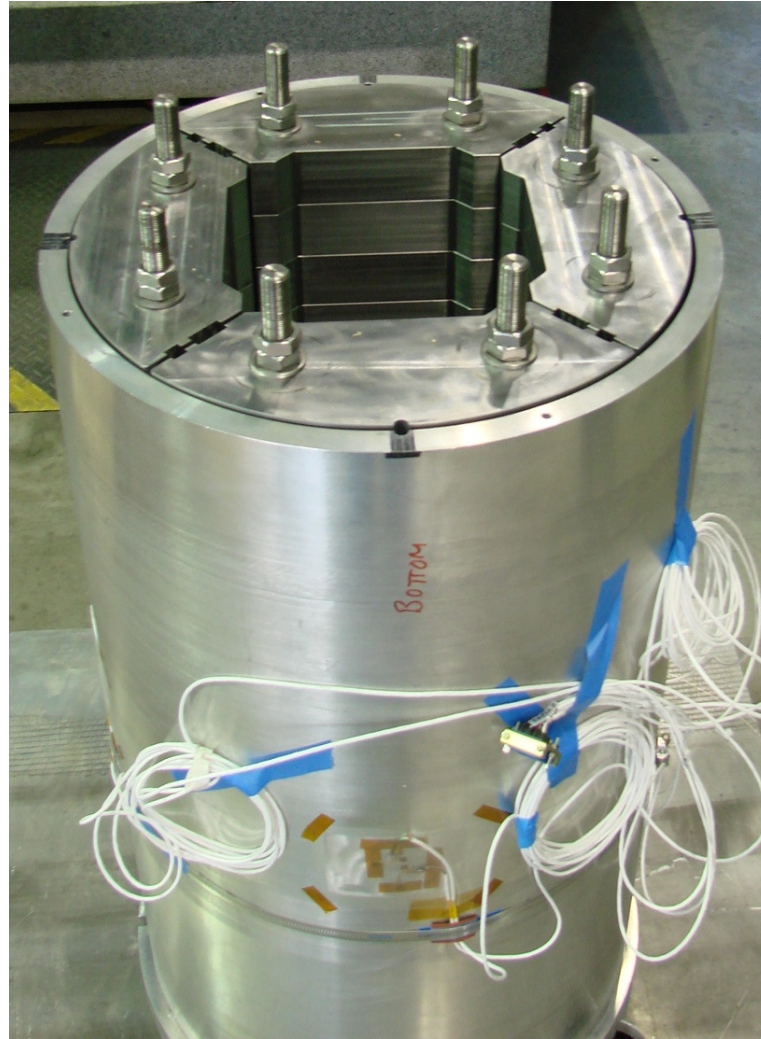
- Yoke rod tension: 330 MPa
- Force on yoke stack: 190 kN



# Assembly and loading of 850 mm long segment

## Insertion of yoke stacks in shell

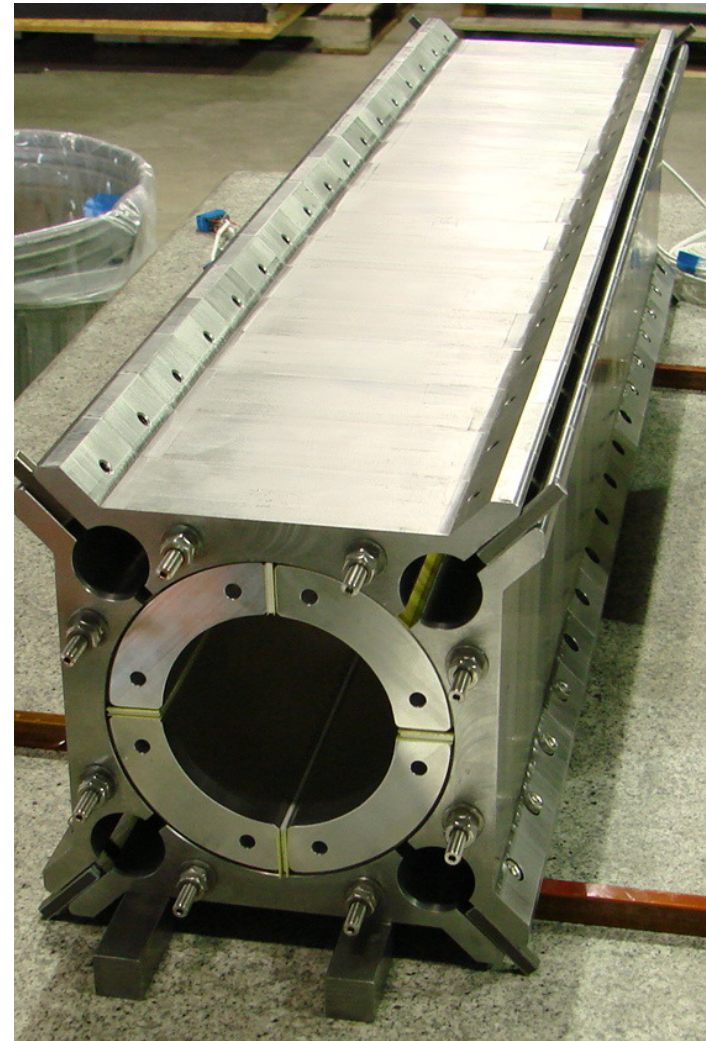
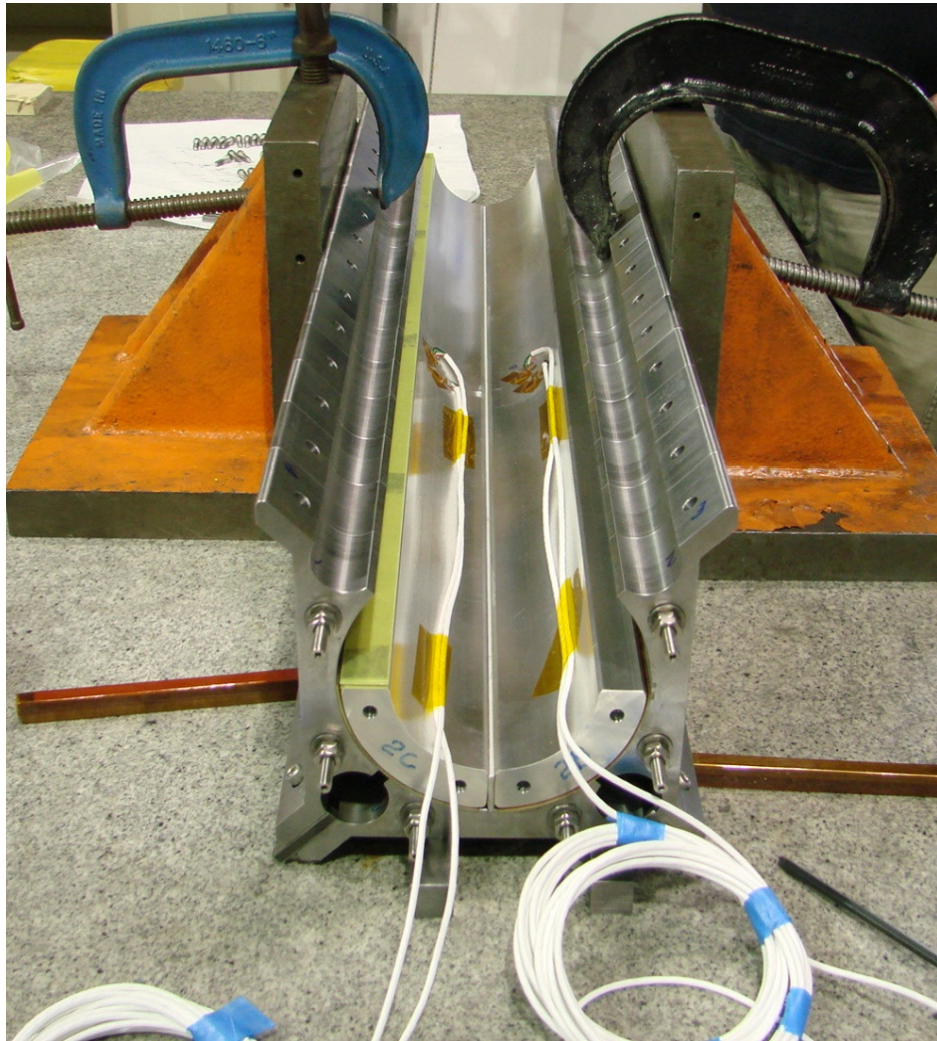
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# Assembly and loading of 850 mm long segment

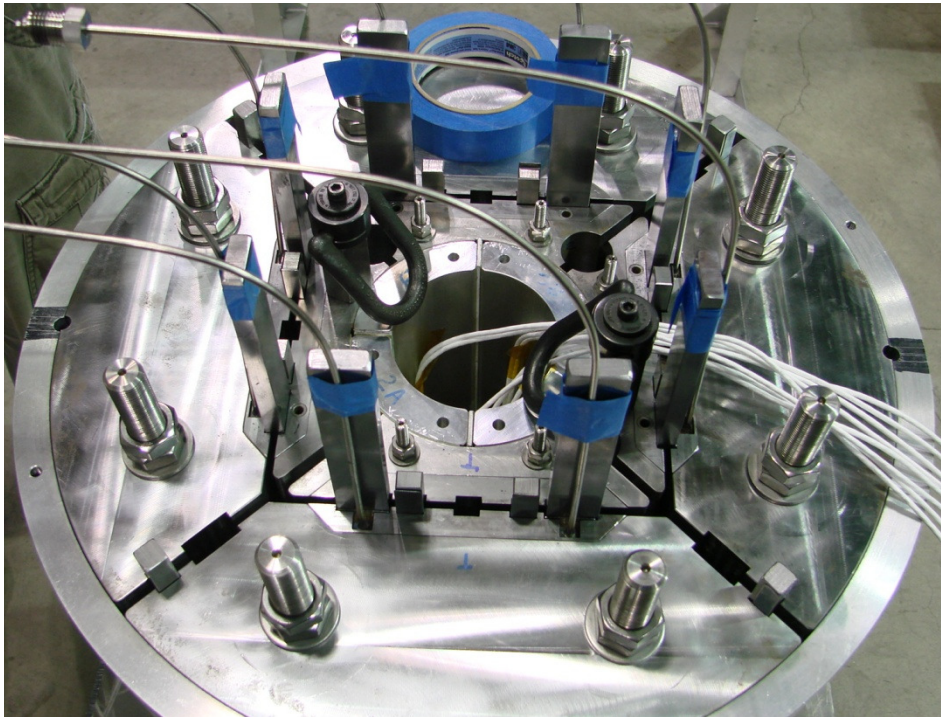
## Assembly of dummy coil pack





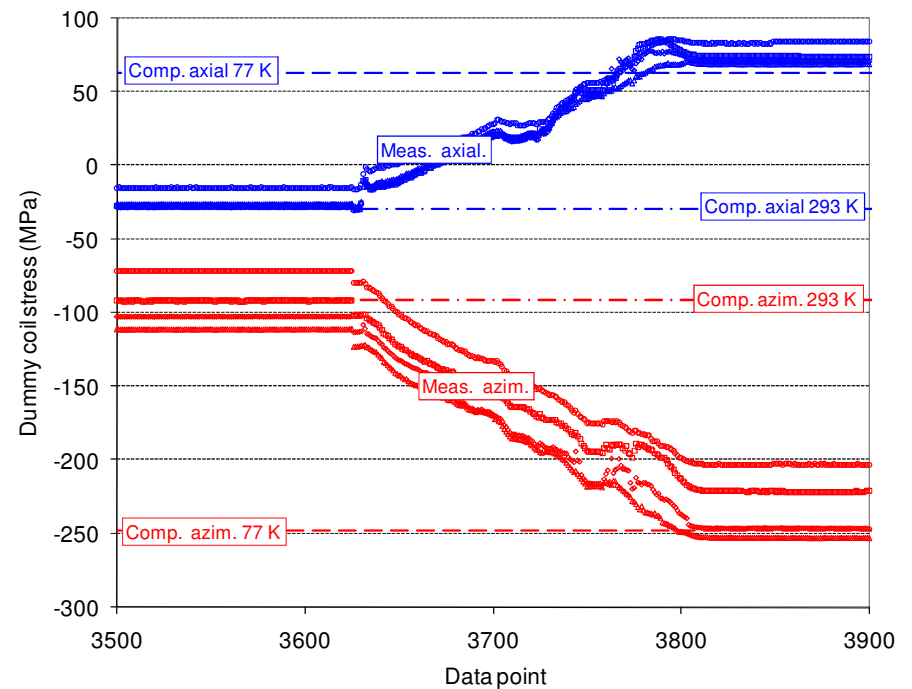
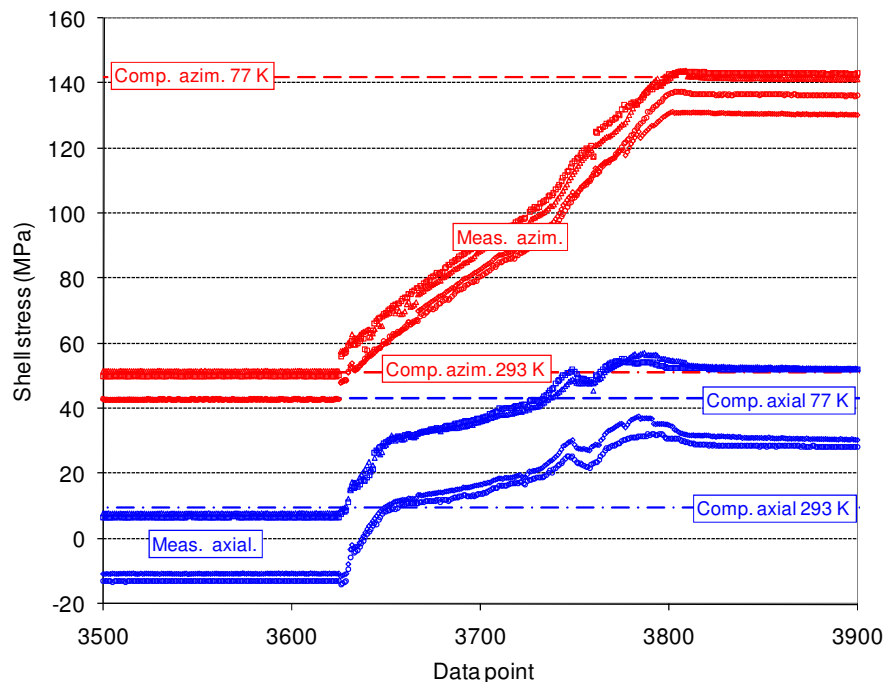
# Assembly and loading of 850 mm long segment

## Loading and insertion in the cryostat



# Cool-down to 77 K of 850 mm long segment

- Shell stress at 77 K
  - Azimuthal:  $+138 \pm 6$  MPa
  - Axial:  $+41 \pm 13$  MPa
- Dummy coil stress at 77K
  - Azimuthal:  $-231 \pm 23$  MPa
  - Axial:  $+74 \pm 7$  MPa

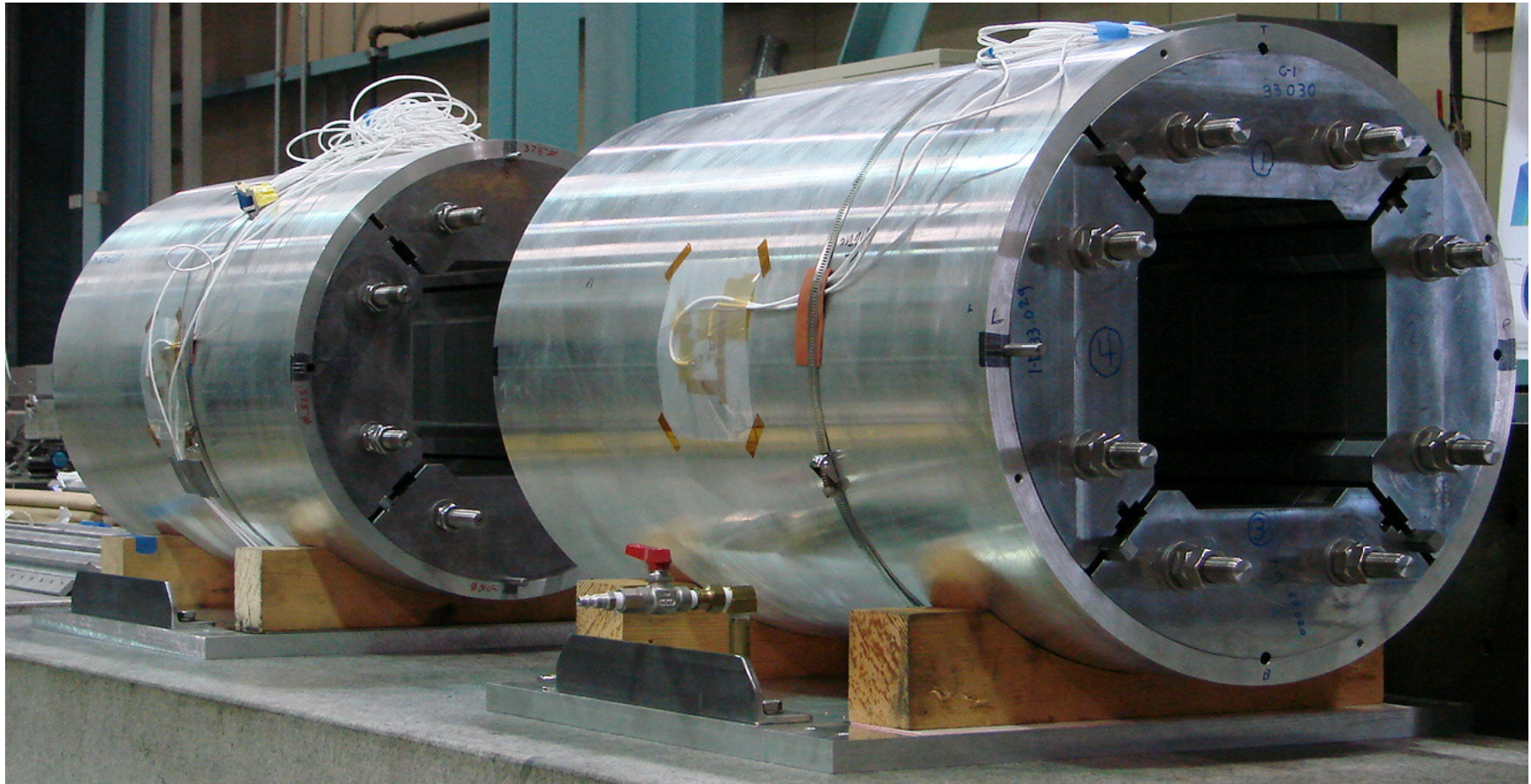




# Assembly of full-length structure

## Section 1 and 2 before joining operation

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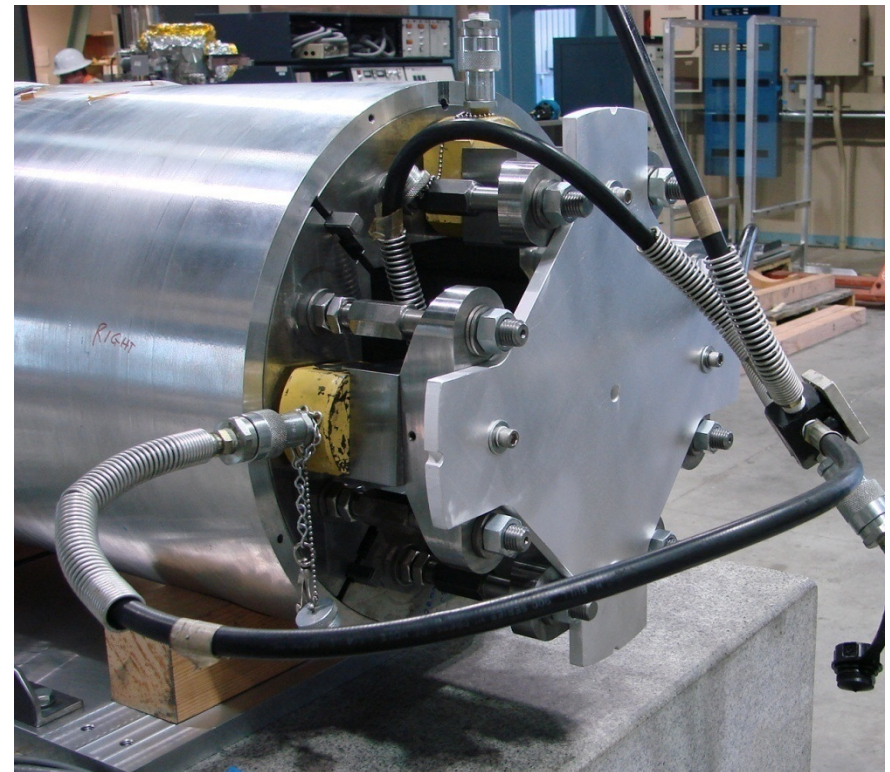
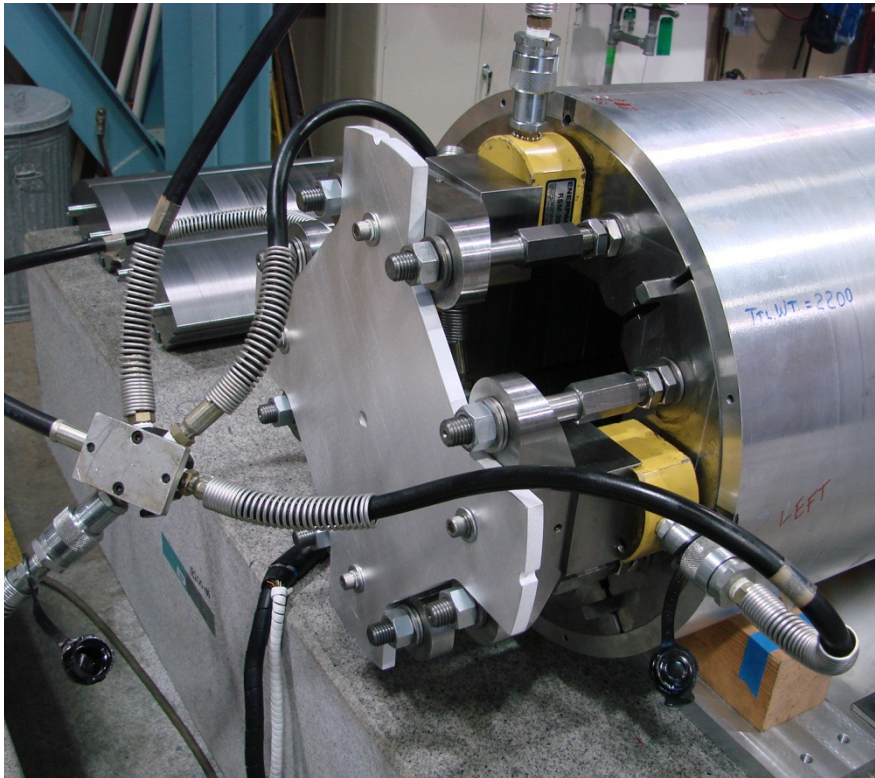




# Assembly of full-length structure

## Removal of 850 mm long yoke tie rods

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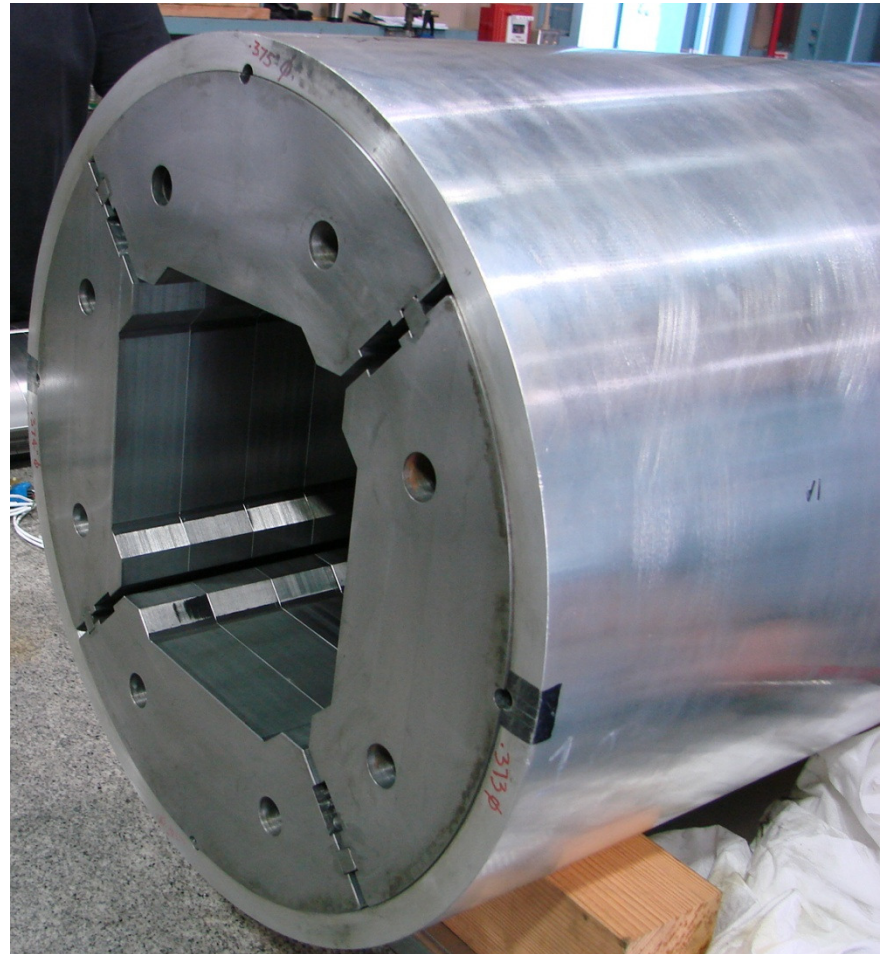




# Assembly of full-length structure

## Preparation of alignment pins and bushings

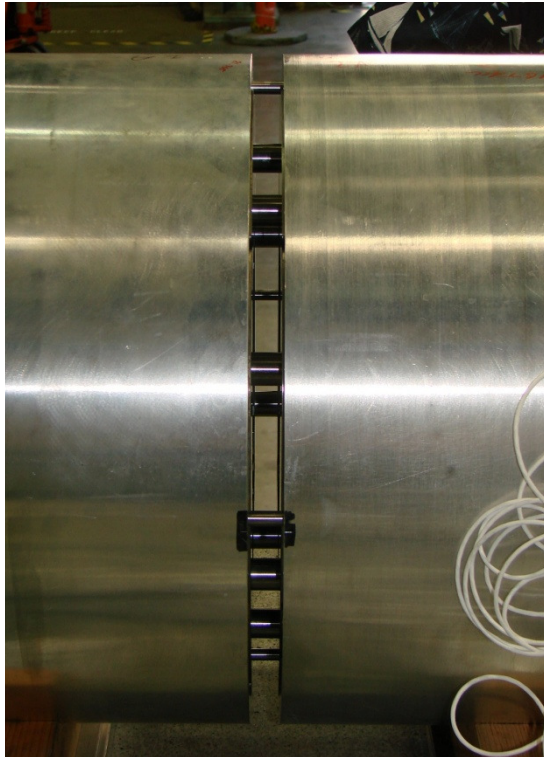
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# Assembly of full-length structure

## Joining operation of 2 segments (I)

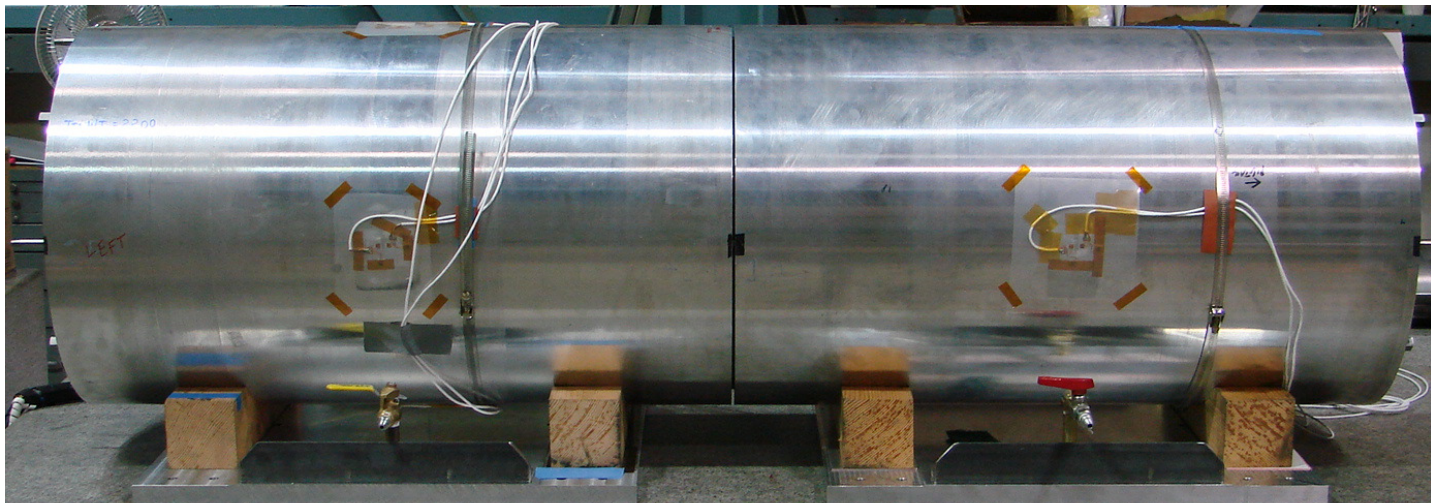
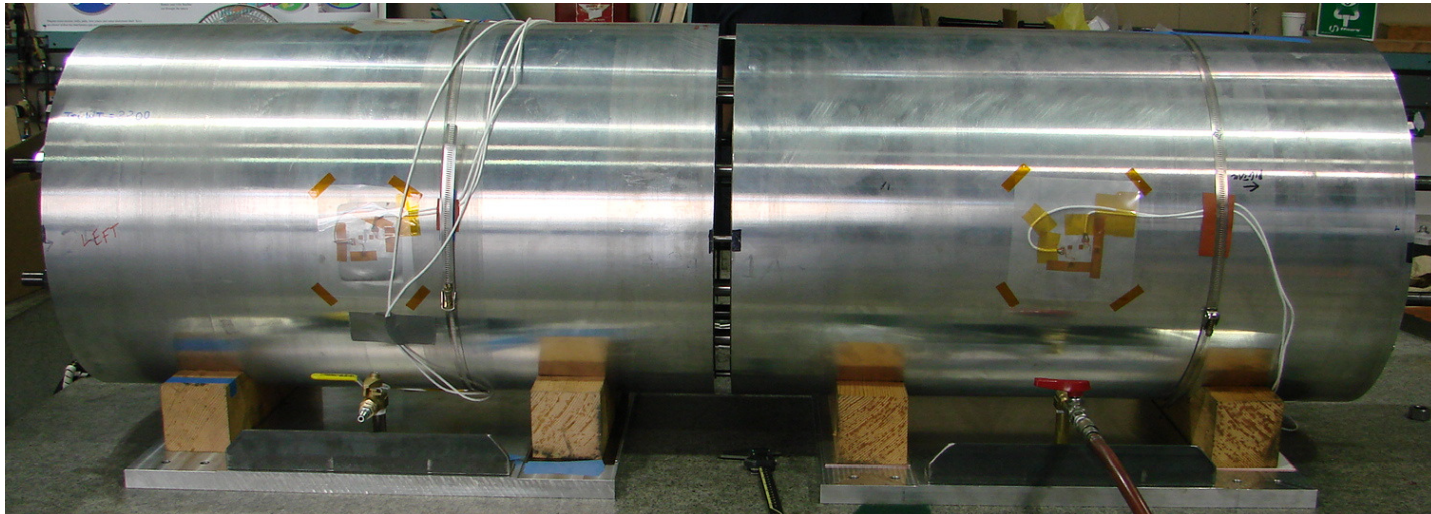
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# Assembly of full-length structure

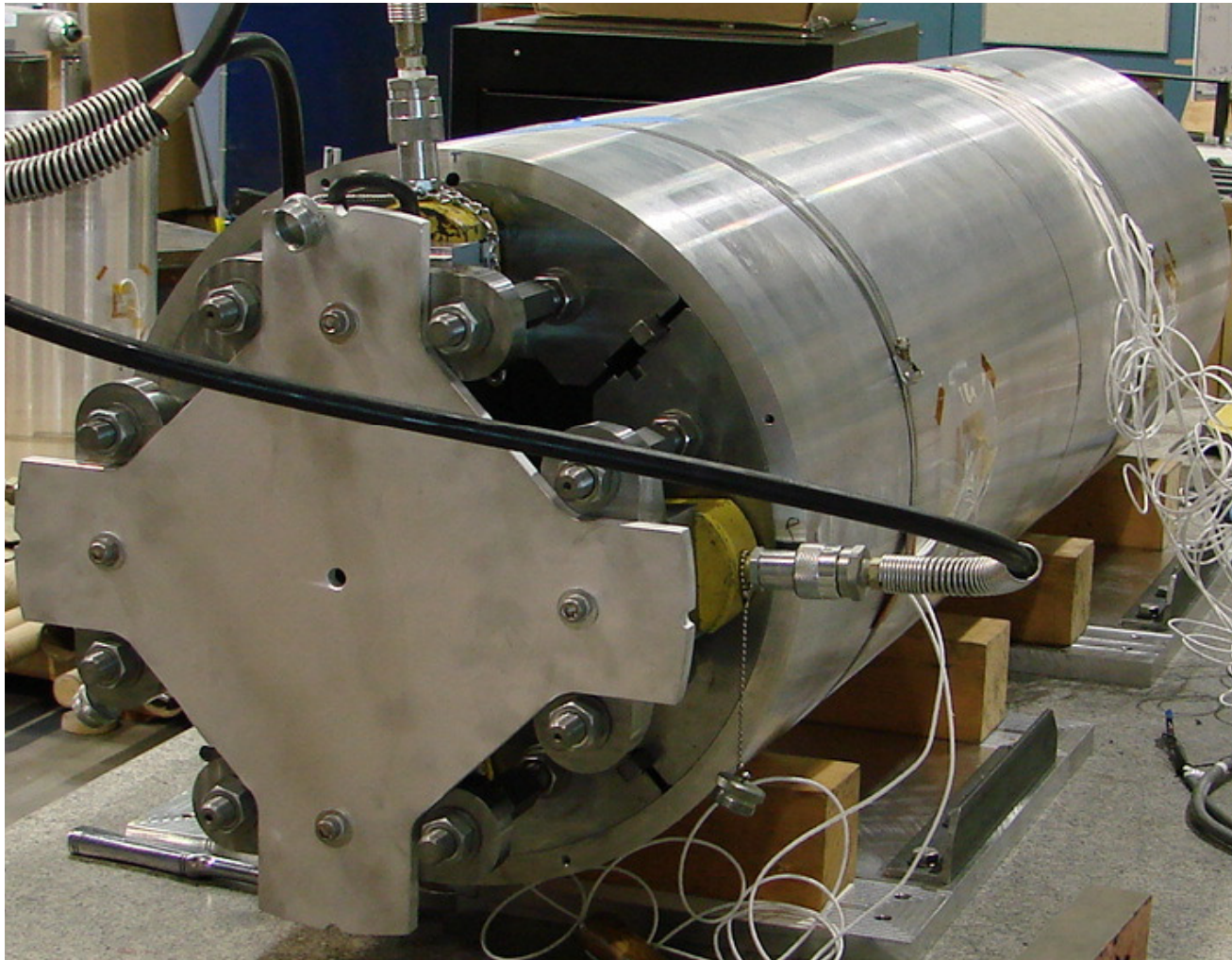
## Joining operation of 2 segments (II)



# Assembly of full-length structure

## Insertion-tensioning of 1.7 m long yoke tie rods

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# Assembly of full-length structure

## Assembly of 1.7 m long dummy coil pack

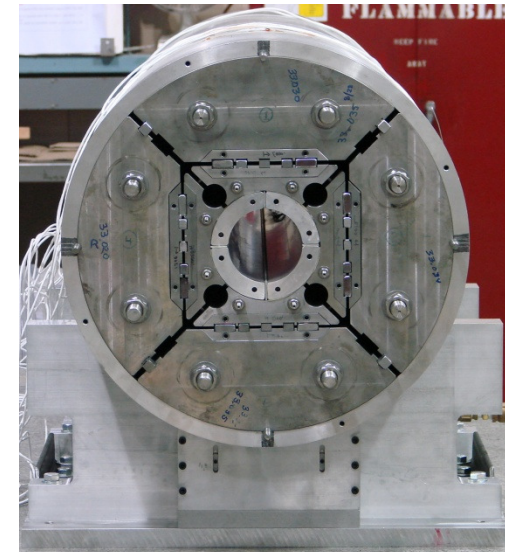
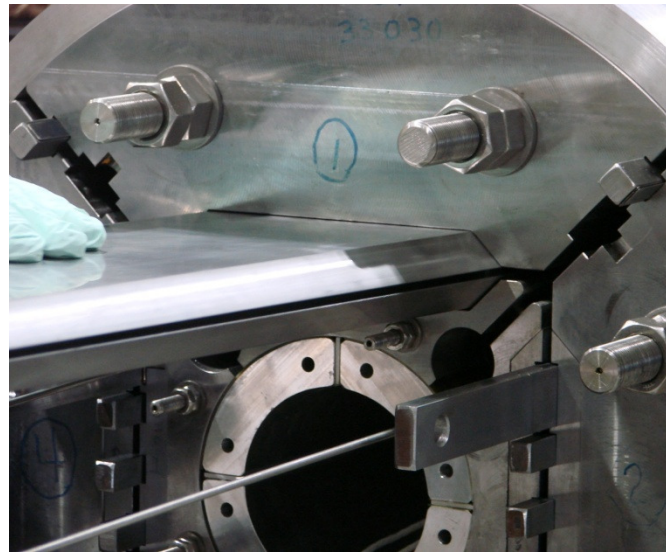
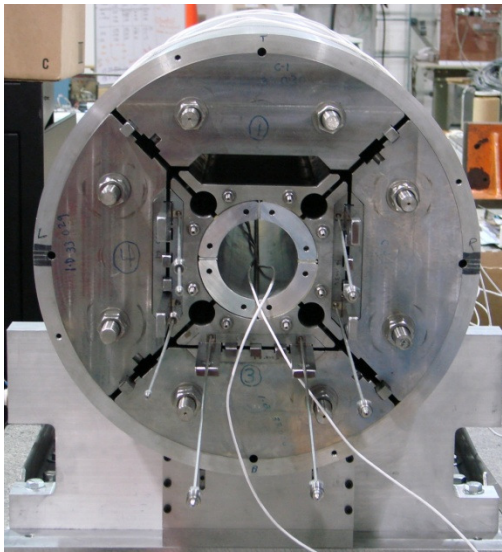
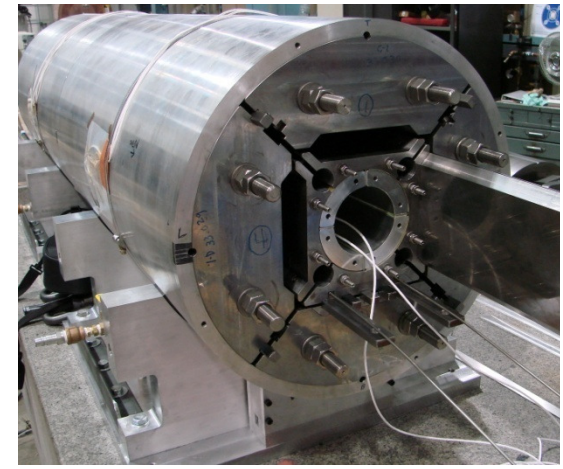
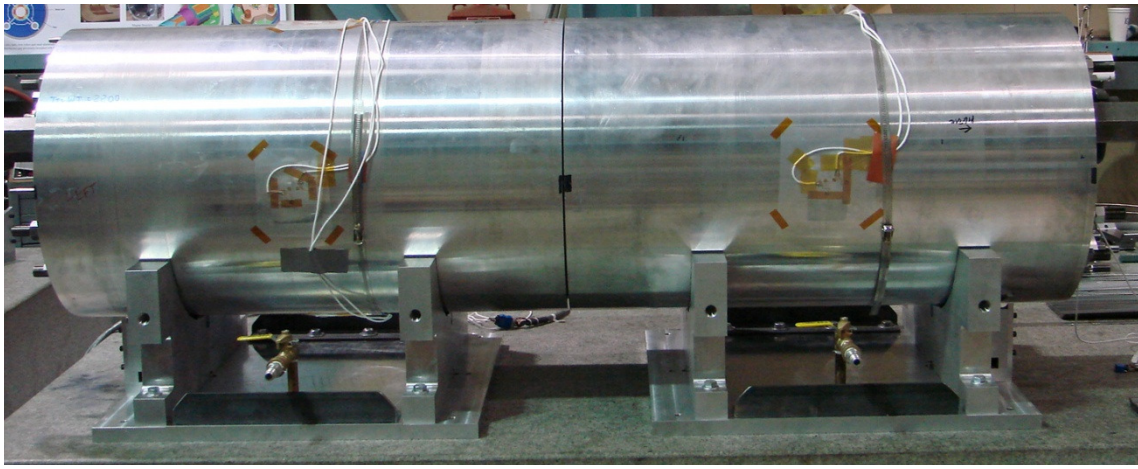
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# Assembly of full-length structure

## Pre-loading and insertion of 1.7 m long gap keys



# Assembly of full-length structure

## Assembly of second segment pair

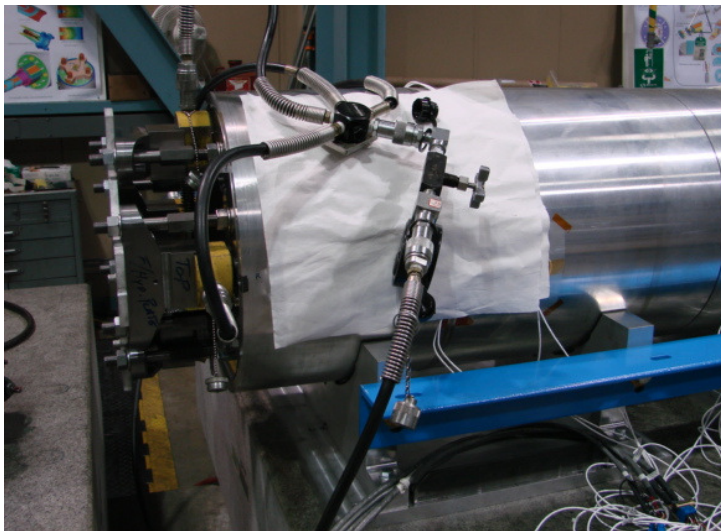
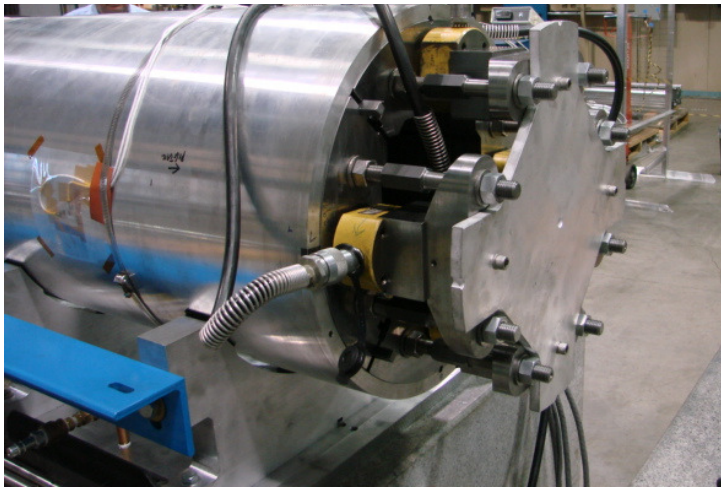
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# Assembly of full-length structure

## Joining operation of 2 segment pairs

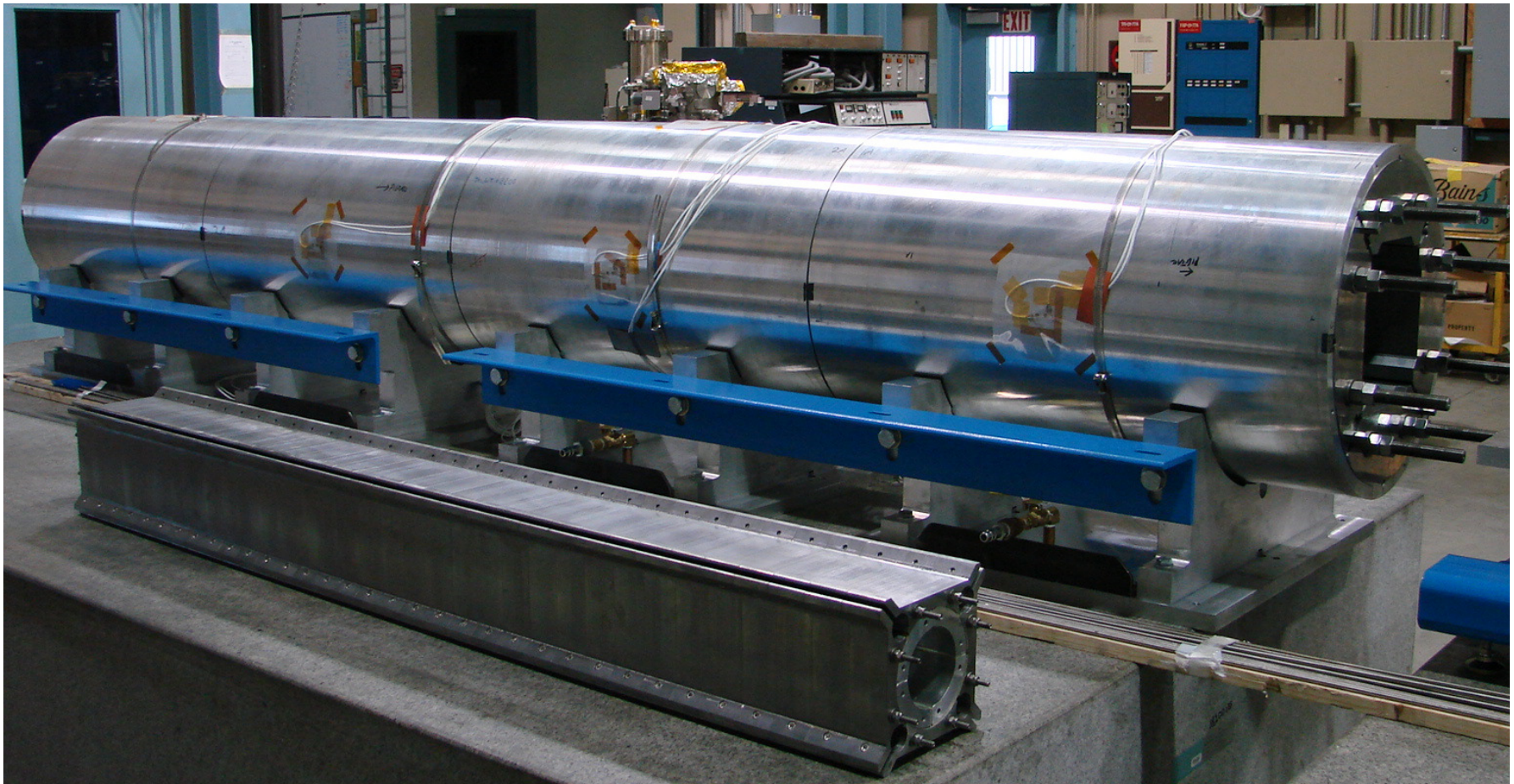


Yoke rod tension: 330 MPa  
Compressive force: 760 kN



# Assembly of full-length structure 3.4 m long yoke-shell sub-assembly

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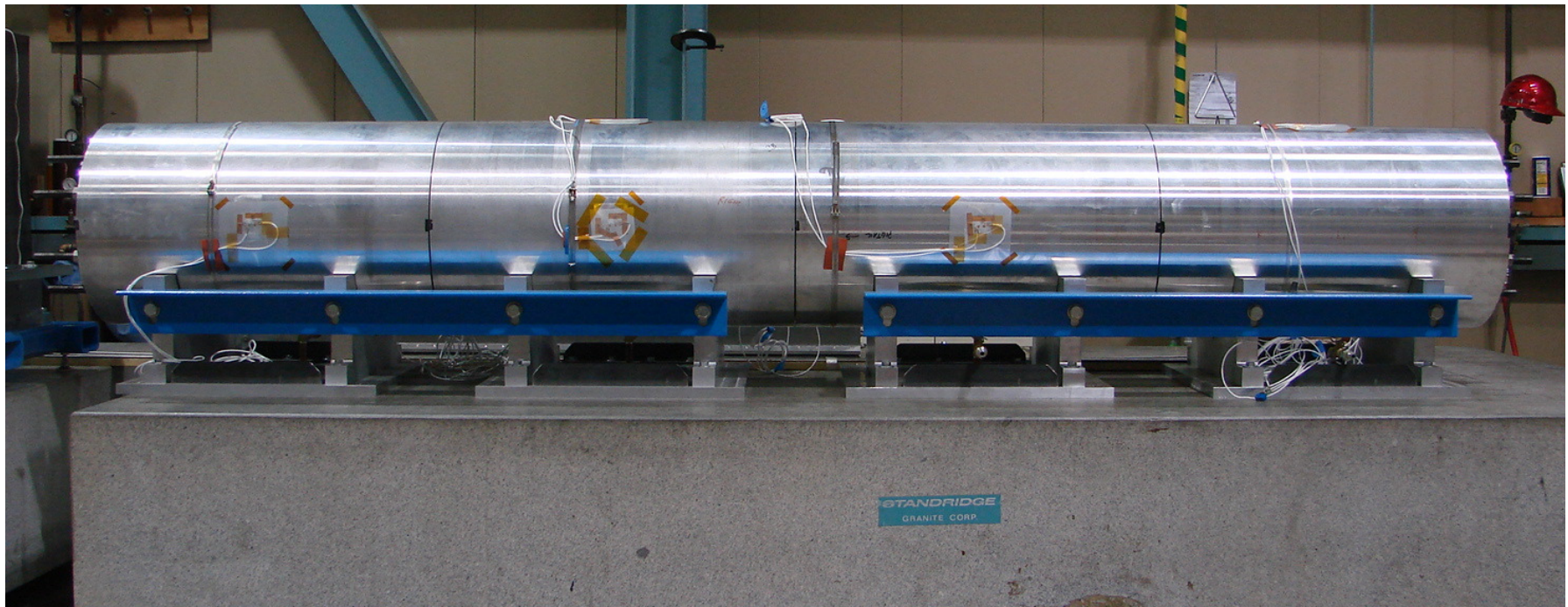




# Assembly of full-length structure

## 3.4 m long yoke-shell sub-assembly

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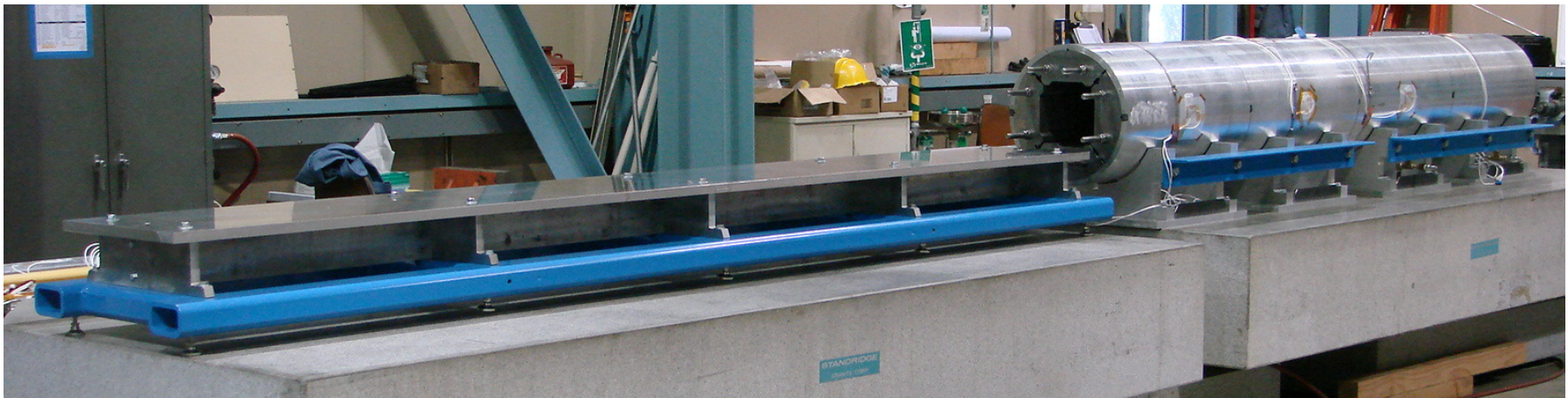
# Conclusions

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- 3.7 m long LQ shell-based support structure (LQS) designed, analyzed with 2D/3D magnetic/mechanical models, and procured
  - Coil supported (no gaps expected) up to 240 T/m
- 850 mm long segment assembled, loaded, and cooled-down to 77 K with dummy coils
  - Strain gauge results consistent with expectations
- Loading with bladders of a 1.7 m long structure performed
  - Same operation as for full-length structure
- Full-length shell-yoke sub-assembly completed
  - Successful implementation of procedure based on short segments

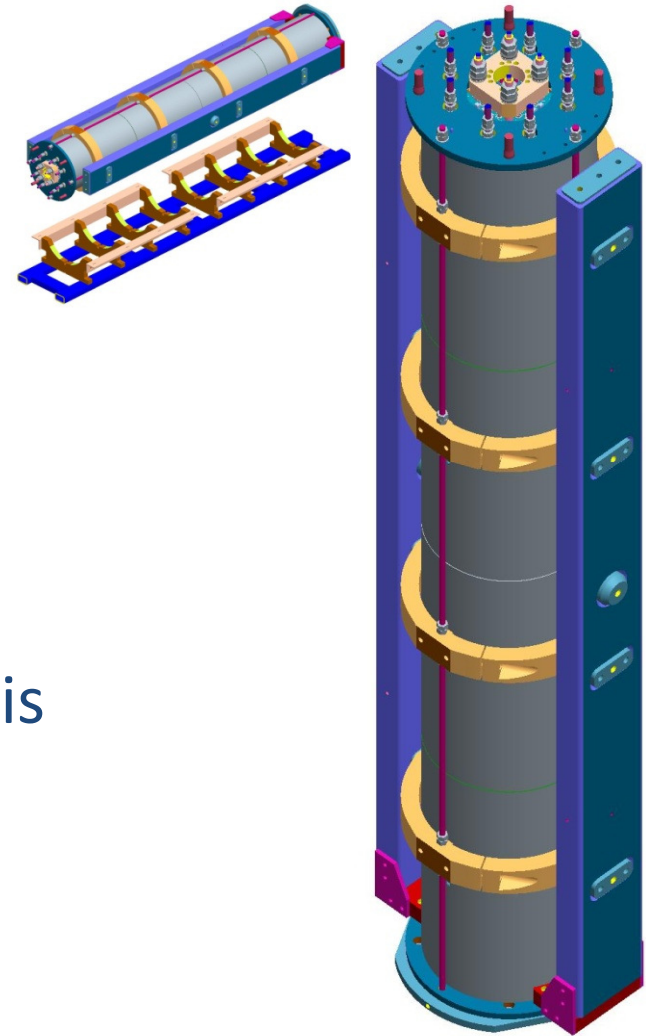
# Next steps (I)

- Assembly of a full-length dummy coil pack
- Assembly and loading of a full-length structure with dummy coils (LQSD)
  - Bladder operation
  - Pressure sensitive film test
  - Pre-tensioning of coil axial support system



## Next steps (II)

- Lifting/tilting tooling
  - Complete procurement
  - Test components
  - Assembly around LQSD structure
- Shipment LQSD from LBNL to FNAL
- Tilting and insertion in the cryostat
- Cool-down test of LQSD and analysis
- Shipment LQSD from FNAL to LBNL
- Disassembly of LQSD



## Next steps (III)

- Tooling for coil-pad assembly
  - Complete design and procurement
  - Test with practice coils
- Assembly and loading of LQS01
  - Bladder and axial loading operations
  - Connection of all instrumentation to connectors mounted on the shell (lead end)
  - Assembly of lifting/tilting tooling
- Shipment of LQS01 from LBNL to FNAL
- Tilting and insertion of LQS01 in the cryostat
- Test of LQS01

